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Final Report for
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Meso-optics Based WDM Receiver

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Executive Summary

The broad goal was to advance the state-of-the art in WDM receiver technology. The approach was to use microcavity resonators since they should enable devices to be very small, rapidly tunable, and with high optical performance characteristics. In order to achieve this goal, design tools -- Maxwell equation solvers -- needed to be developed capable of handling long time spans in complex, 3D geometries. Currently demonstrated devices have been designed with much less computationally-demanding 2D, short time span programs. However, although conceptually simple, these devices are very difficult to fabricate as the precision features are on the surface, horizontal plane of the semiconductor chip. However, by altering the configuration so the most demanding features are vertically-separated layers, fabrication could be greatly eased though using epitaxial growth which is capable of forming very thin, very well-controlled layers. In addition, it may be possible to design complex structures that decrease the need for sharp, large index changes, which also are difficult to fabricate, without unduly compromising performance. For the complex-3D geometries that are required, intuition is often misleading and the use of accurate design tools is essential.

To advance the goal of developing high-performance, easily to fabricate WDM microcavity components, we:

- fabricated some prototype 3D designs in a new polymer material, with limited success.
- designed and sent out for fabrication 3D semiconductor devices
- designed and largely completed a special instrument at NIST to characterize the optical properties of guided-wave microcavity devices
- converted the CalTech design code to run on the San Diego Tera supercomputer, which required considerable low-level I/O coding for that early-stage system
- inserted the recently-developed memory- and cycle-saving Cole non-standard finite difference algorithm into the Tera code making large-scale 3D designs feasible in principle (not a user-friendly program as it stands)
- began implementing animated visualizations based on an open-source package which would make remote visualization of the computationally-intensive core Maxwell solver accessible on remote, generic UNIX/Linux platforms

Because the funding for this effort was abruptly terminated, none of these efforts reached a satisfactory plateau such that solid results can be shared within the scientific community.

Background

Most current architectures for tunable WDM communication systems use tunable transmitters and passive receivers due to the difficulty in making a rapidly-tunable receiver. In fact, it might be argued that all designs for rapidly tunable receivers are unsatisfactory. However, rapidly tunable transmitter systems that are also inexpensive to manufacture and operate are also a technological challenge. Microcavities, with their ability to select a narrow linewidth from a neighboring waveguide, offer a potential solution. In addition, if the coupling can be made rapidly tunable by being changed by a semiconductor current-induced index change, the resulting device should be at the mm scale in size, tune at ns speeds, and select narrow linewidths during operation. If such a device can be manufactured with tolerance ranges that don't degrade performance, WDM communication technology would be considerably advanced. At the time of the proposal, only passive fiber + microcavity/microdisk devices had been demonstrated with the geometry defined by electron beam lithography. Because of the need for very tiny and precise fiber/microcavity coupling regions formed on the chip surface, the yield of useful devices was very low but the concept was proven in principle.

The concept behind this proposal was to take advantage of the ability to form layers with atomic precision by epitaxial growth. By changing the 2D original geometry of the fiber + microcavity/microdisk device to a 3D geometry where the coupling regions were electro-optic, precision-width layers, not only would the device be far easier to fabricate but also rapidly tunable. It was also hoped that a more complex 3D geometry could be used to mitigate the need for very sharply defined microcavity/microdisk boundaries with index contrasts near the limit of feasibility. The 3D geometry would necessarily be more complex and much harder to model because of the increased memory and cycle demands on the Maxwell solver program. In fact, the modeling program in 2D for simple geometries running on high-end PCs could not be scaled up for the 3D geometries contemplated to run reasonably even on much larger machines. Then, to complete the contemplated project, more efficient Maxwell solver algorithms would have to be implemented. This algorithm and computer effort was to be carried out by a post-doc, a summer visiting professor, and partially by an undergraduate and two ECE professors.

Once designs were specified, the intent was to fabricate them through Axel Scherer's group at CalTech who obtained companion funding for this purpose, and measure and characterize fabricated device performance in Boulder. For the characterization, suitable optical instruments weren't really adequate. However, a prototype of a suitable device had been developed at NIST and the intent was to reimplement and improve the NIST instrument and use it to characterize to CalTech devices. The PhD student on this project would work at NIST part time on this latter project, and companion funding was also made available to NIST for this. The post-doc would also contribute to this characterization effort.

Approach

The approach taken was to assemble a team with the appropriate talents:

- Steven Huh, post-doc, degree in ECE (optics, computing)
- Punit Kalra, ECE PhD student (optics)
- Ted Brannan, ECE UG/MS degree (electromagnetics)
- Shahid Bokhari, visiting CS prof (supercomputing)
- Harry Jordan, ECE and CS prof (physics, supercomputing)
- Jon Sauer, Physics and ECE prof (coordination, physics, supercomputing)

The PhD student was to design devices to be fabricated at CalTech and MOSIS, upgrade the NIST instrument, and characterize the devices built.

The post-doc was to provide user interfaces for visualization, to smooth access to the array of computing platforms to be used, and to assist the PhD student in the optics design efforts.

The UG/MS student was to acquire and help retrofit new algorithms into various Maxwell solvers obtained from various sources.

The ECE profs were to make sure the underlying physics embedded in the codes remained correct after modifications, and to port the codes to the UCSD Tera supercomputer.

Hardware

In the first 18 months, the PhD student:

- Visited CalTech to learn their design and fabrication technology.

- Designed and fabricated a few fluorinated polymide polymer devices (Ultradel 9120D) at CalTech using developing solutions acquired from Amoco Chemicals. These low-cost prototype devices unfortunately did not prove to have the mechanical stability and fabrication precision that were hoped for, and, after several months, this effort was suspended.

- Nearly completed a rebuilding and redesign of the NIST waveguide device characterization instrument.

- Designed and sent out for fabrication, to a contract fabrication facility, prototype 3D fiber + microring devices.

Both of the latter efforts were abruptly halted without reaching a reportable status with the suspension of support. Shortly thereafter the student left academic life without completing his PhD and now works for Xilinx designing high performance, field programmable, VLSI gate arrays. The NIST project leader, Matt Young, left NIST to become a semi-retired EE prof at the Colorado School of Mines.

Analysis and Software

Finite-difference, time-domain codes were obtained from Axel Scherer's group at CalTech, from James Cole at NRL, and Cray Research (a code largely developed by Melinda Piket-May, now a Boulder prof, for her PhD). Jelena Vuckovic from CalTech visited Boulder to help port the elaborate PC/Linux-based CalTech code to the stripped-down software environment on the Tera. The James Cole code incorporates a new non-standard FD technique that is both more accurate and demands less computational resources than the standard approach. James Cole made two visits to Boulder to help us with his code. Melinda Piket-May also discussed contributing a prototype FD code incorporating the ADI (alternating direction implicit) technique, which also is an improvement over the standard approach.

The CalTech code was successfully ported to the Tera, and a start was made in retrofitting the Cole algorithm into this code. Because of the immaturity of the Tera environment, we had to do considerable low-level system programming to improve the Tera's I/O to input and output the large data sets we required. A paper describing this effort is included. A comparison was made of performance of finite difference and related codes on the Tera with respect to other more conventional supercomputer architectures. On the Tera, the effects of the number of processors utilized for large problems was examined. This effort involved examining the behavior of the Tera as the number of processors as well as the resources per processor were varied. The code run

solved the Euler equations on an unstructured mesh, which are notoriously difficult to parallelize on conventional supercomputers. On the Tera parallelization was straightforward and we were able to obain detailed performance characteristics. A paper describing this study is also included.

In spite of considerable effort, the Cole code, although ported to the Tera, never gave physically consistent results due to implementation bugs that were never completely sorted out.

A good start was made on separating the computational core of these codes from the visualization so, for large production jobs, the Tera could perform the numerical computations remotely but the results could be viewed locally on PC-level hardware. The intent was that interactive visualization of the performance of complex photonic band gap systems could greatly speed design.

At the time of support suspension, the ADI and Cray efforts hadn't yet begun.

Within a week of funding suspension, the post-doc had found a new job and left the university two weeks later. Steven now works at CellPort designing hardware and writing low-level software for wireless, hands-free car phones. The UG/MS student left the optics area, and is now doing a MS thesis in electromagnetics in another group.

Future Prospects

It will not be possible to rejuvenate the hardware effort for an effort of less than 2-3 years as PhD hardware efforts are inherently on this scale. Thus, for the follow-on proposal now being considered for funding, we have concentrated on the lower-cost, analysis and software portions of the original proposal done by profs and MS students. Basically, in one year at about 1/3 the cost of the remaining time in the original proposal, we hope to complete or nearly complete the analysis and software portions originally envisioned.

Conclusion

The broad goal was to advance the state-of-the art in WDM receiver technology. The approach was to use microcavity resonators since they should enable devices to be very small, rapidly tunable, and with high optical performance characteristics. In order to achieve this goal, design tools -- Maxwell equation solvers -- needed to be developed

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Reasonable progress was being made on most aspects of the effort when funding was abruptly suspended. The impact on the personnel assembled in the team was considerable. It is thus impossible to resume the original hardware portion on the scale of a year even if funding were available. We have therefore proposed a reduced-scale effort to complete the analysis and software portions of the original proposal as we feel this project still can make an important impact in the area of photonic band gap devices.